# PAM: ANTS-based Biologically Inspired Mission Concept, Components, and Requirements for an Asteroid Population Survey

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## Mainbelt Asteroids: Knowledge Limited without Survey

| Type of Observation/Primary Source | now | 2025 |
|---|---|---|
| Orbits/Magnitude/Ground Telescopes | ~$10^5$ | $10^6$ |
| Light curves/Ground Telescopes | ~5,000 | 50,000 |
| Visible spectra/Ground Telescopes | ~2,500 | 25,000 |
| IR measurements/IRAS | ~2,500 | 25,000 |
| Surface properties/Ground Telescopes | ~100 | 1,000 |
| Shape models/Spacecraft,HST,Ground Radar | ~10 | 100 |

## Asteroid Survey Challenges

Large number of targets or extensive area.

Wide range of instruments and operational requirements.

Inaccessible and/or remote terrain.

Large Delta V requirement for ‘fully loaded’ spacecraft.

## Asteroid Survey Requirements

Optimal science operations at each object and concurrent operations at many objects.

Ongoing evolution of tactics and strategies as a function of object characteristics.

No single point failure, robust to minor and catastrophic loss.

Highly autonomous constellation of specialized workers.

## ANTS Solution:
## Prospecting Asteroid Mission Concept

An insect colony analog:
(Worker, Messenger, Leader).

Large number of very small spacecraft.

Very specialized spacecraft.

Solar sails for Delta V.

Highly autonomous operation

## PAM Characteristics

- "target of opportunity" asteroid survey
- search for resources, evidence for life
- 1000 spacecraft swarm
- 10 specialist classes with common bus
- 10 to 20 subswarms concurrently operating
- subswarm@1 month/asteroid, 5 asteroids/year
- 100's of asteroids in 5 year traverse of belt
- Operation at low target density, low G
- Propulsion: solar sails
- Power: nuclear batteries

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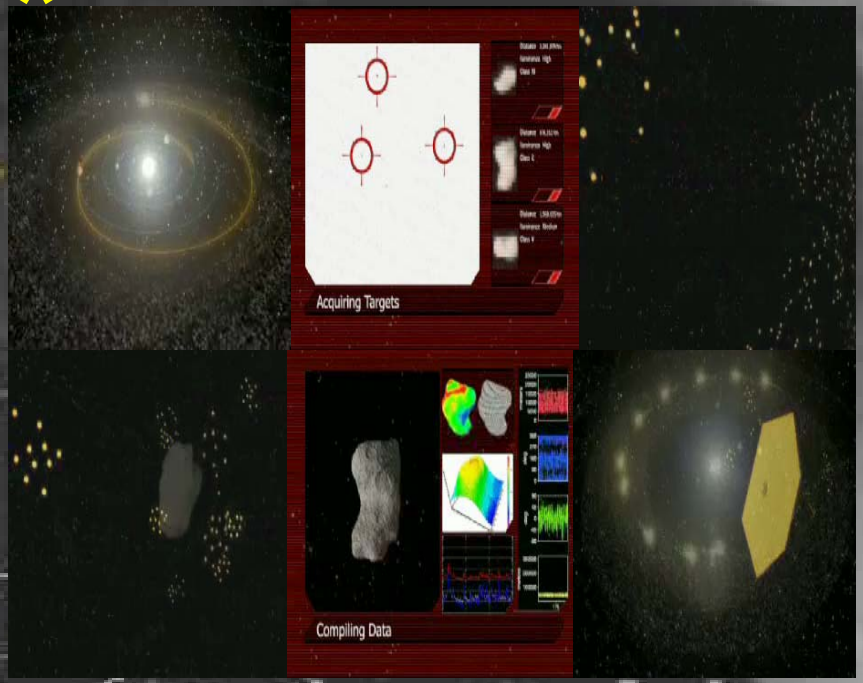


## PAM Synopsis

a) After in space deployment and launch of individual spacecraft, swarm follows a Solar Sail Outbound Trajectory to asteroid belt.

b) Potential targets of opportunity are detected by Imagers. As targets are selected, based on proximity or scientific interest, subswarms leave the swarm and head for the target.

c) Within each subswarm, virtual instrument teams form from each instrument class to perform preliminary reconnaissance of asteroid in the most advantageous orbit for that instrument. This could be followed by formation of virtual experiment teams from different instruments.

d) Analysis of measurements made of asteroid by all instruments is performed meanwhile by leaders/messengers in each subswarm.

e) Messengers return to download data at point nearer Earth as required.

## Mainbelt Asteroids: Unanswered Questions

1) What is the true distribution of elements, minerals, rock types, parent bodies from early solar system, and potential resources? Where are the olivine-dominated samples of parent body 'mantle' and chondrites which, according to models and the meteorite collection, should dominate?

2) What is the nature of regolith formation and modification in space (Space Weathering) and its potential use for construction?

3) What is the nature of the relationship between dynamical and compositional properties in the small body population, and, by implication, in the early solar system?

# PAM Virtual Instrument Teams

| Specialization Class | Primary Task, Requirements |
|---|---|
| Leader | Processing, Strategizing, Out of the way but within range |
| Messenger | Communication, Out of the way but within range |
| Workers: | Data Gathering |
| Imaging (Visible) | Target Detection, 3D Model, Photogeology/ some illumination |
| Visible/IR Spectrometer | Mineral Abundances/Close, Nadir, Full sun |
| X-ray Spectrometer | Major Elements/Close, Nadir, Full sun |
| G-ray/Neutron Spec | Heavy Element/Volatiles/Close, Nadir, Fill FOV |
| Altimeter (Ranging) | Shape, 3D Model, Morphology/Nadir Pointing |
| Radio Science/Magnetometer | Gravity/Magnetic fields, Interior, 3D Model/Over poles |
| Radio Sounder/IR Radiometer | Regolith Characterization/Close, Nadir |
| Neutral Mass Spec | Volatile Characterization/Close, Full sun |

## PAM Survey Requirements

Launch Date: 2025
Duration, Location: 10 years, 1.0-3.5 AU
Environment: low G, adequate illumination, low density dynamic targets
Spacecraft Mass: 1 kg
Spacecraft Materials: 1 to 5 g/cm$^2$
Power system and mass: Nuclear batteries 0.25 kg
Power requirement: 100-300 mWatts
Propulsion system and mass: Solar Sail 0.5 kg, 103 change in effective sail area
Engineering: 3-axis stable spacecraft, MEMS level components
Deployment Temperature: 40 deg C
Operations:

- Deep space with no direct link to Earth
- Individual craft (Messenger) return data
- One month of optimal science/asteroid
- Full instrument suite deployed/asteroid
- Concurrent operations at ~10 asteroids
- No single point failure
- Robust to minor faults and major failures
- Optimal operations in spite of 10% attrition/year

# ANTS Architecture Assembly

PAM components and spacecraft assembly (below) and deployment sequence (on the right).

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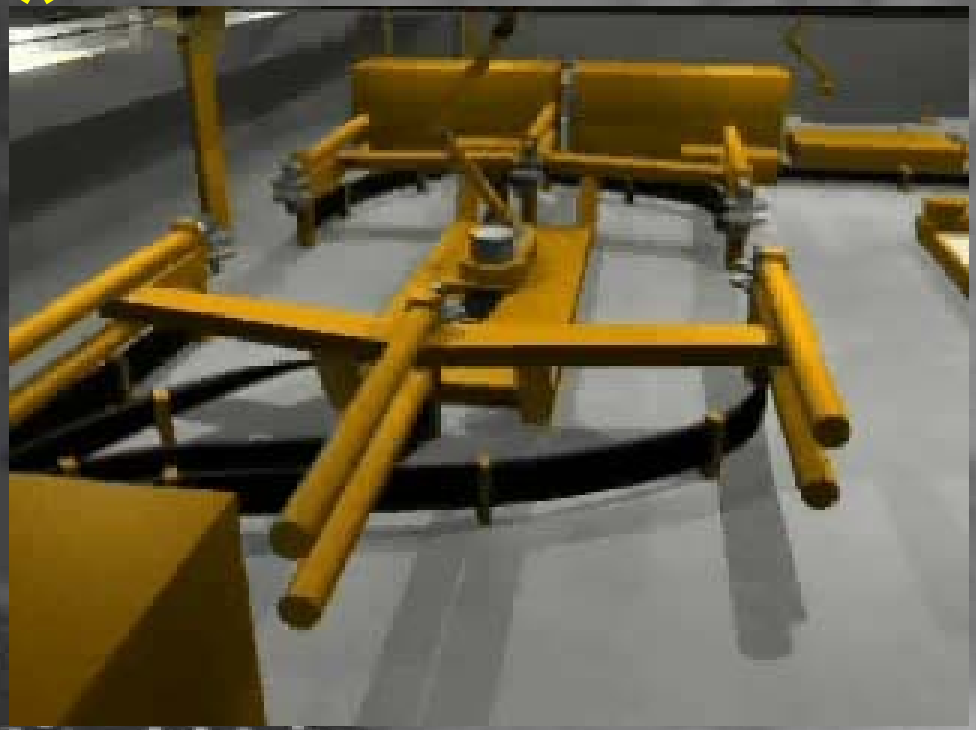

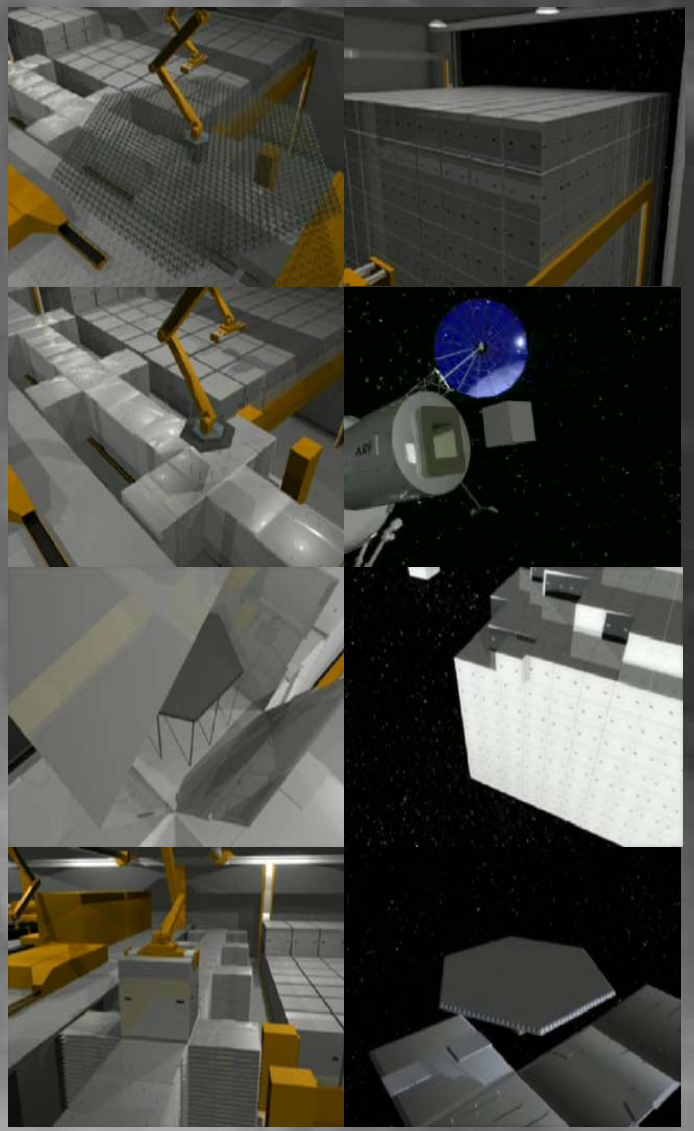

MEMS Node spooling mechanism design and relative size of nodes on 2000 penny.

**PAM Deployment sequence**:

Launching of PAM spacecraft,
Expansion of space frame, and
Deployment of instruments on space platform tethered to space frame in simulation below.

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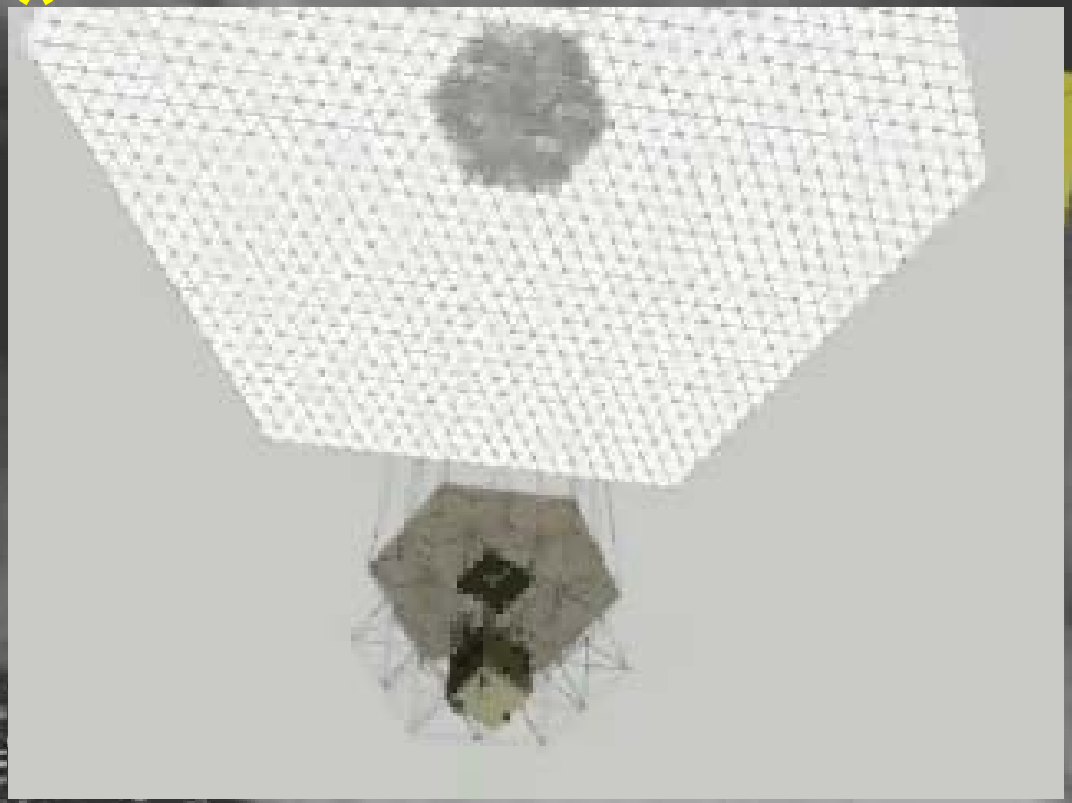
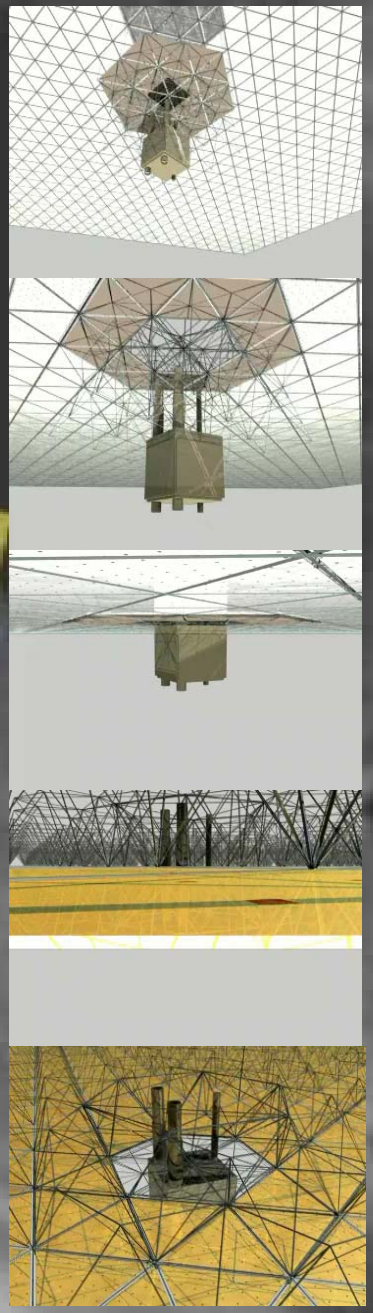


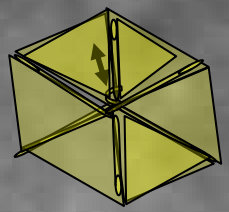


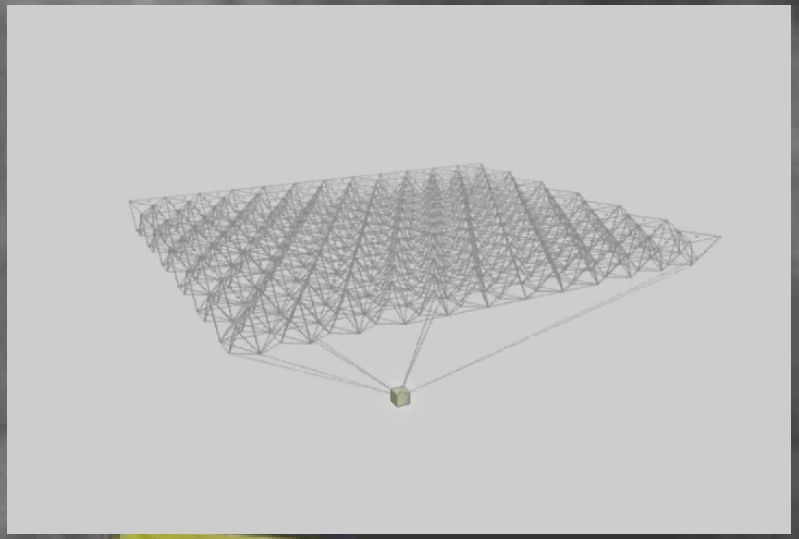
## PAM Solar Sails

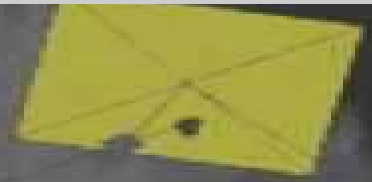
Capable of attitude control by changing center of pressure through controlling deployment of individual facets.

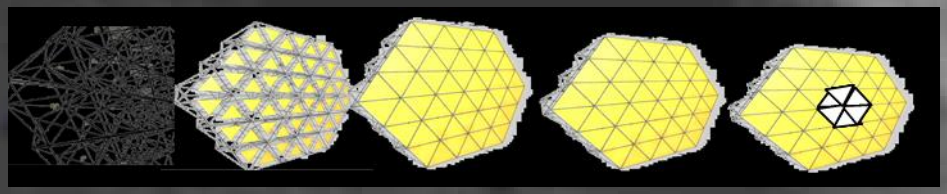
Capable of attitude control through changing morphology. This same capability allows self repair.

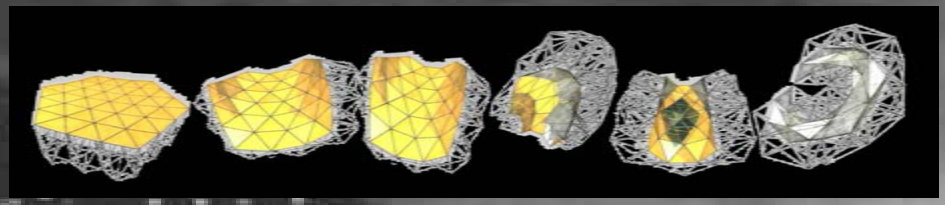
Carbon-Based Sail Deployment Mechanism

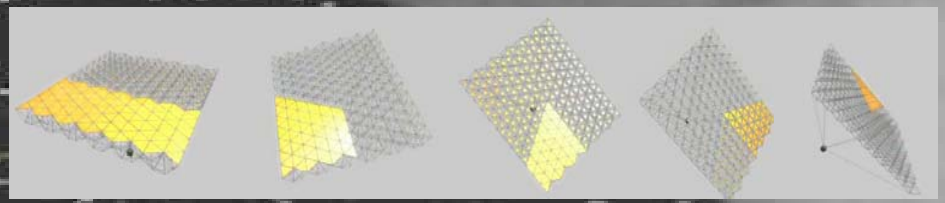


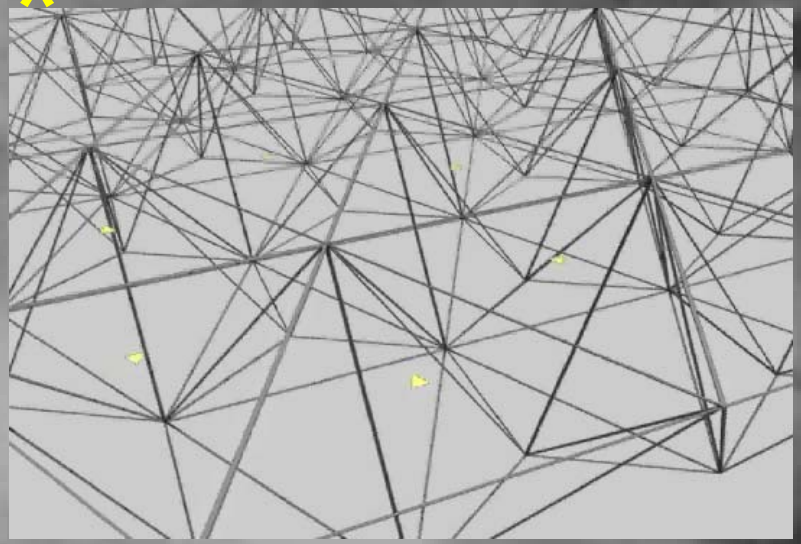












## Conclusion: PAM Addressable Reconfigurable Technology is feasible

Required incremental improvements in low mass 100's mWatts output nuclear batteries and low mass communication, navigation, and tracking devices are anticipated.

Carbon fiber based materials are already at the threshold of the minimum aerial density requirement of 5g per square centimeter, inculding structures either embedding CNTs in polymer matrix (surfaces or ropes) or directly using CNTs.

Autonomous navigation without appendages is currently being developed through our tetrahedral walker prototype.

The potential flexibility and adaptability of such a system demands a level of artificial intelligence we are in the process of developing through our role in ST-8 COTS High Performance Computing and Multi-agent Simulations using Beowulf clusters.

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